NRTC/CRI
Rotorcraft Damage Tolerance

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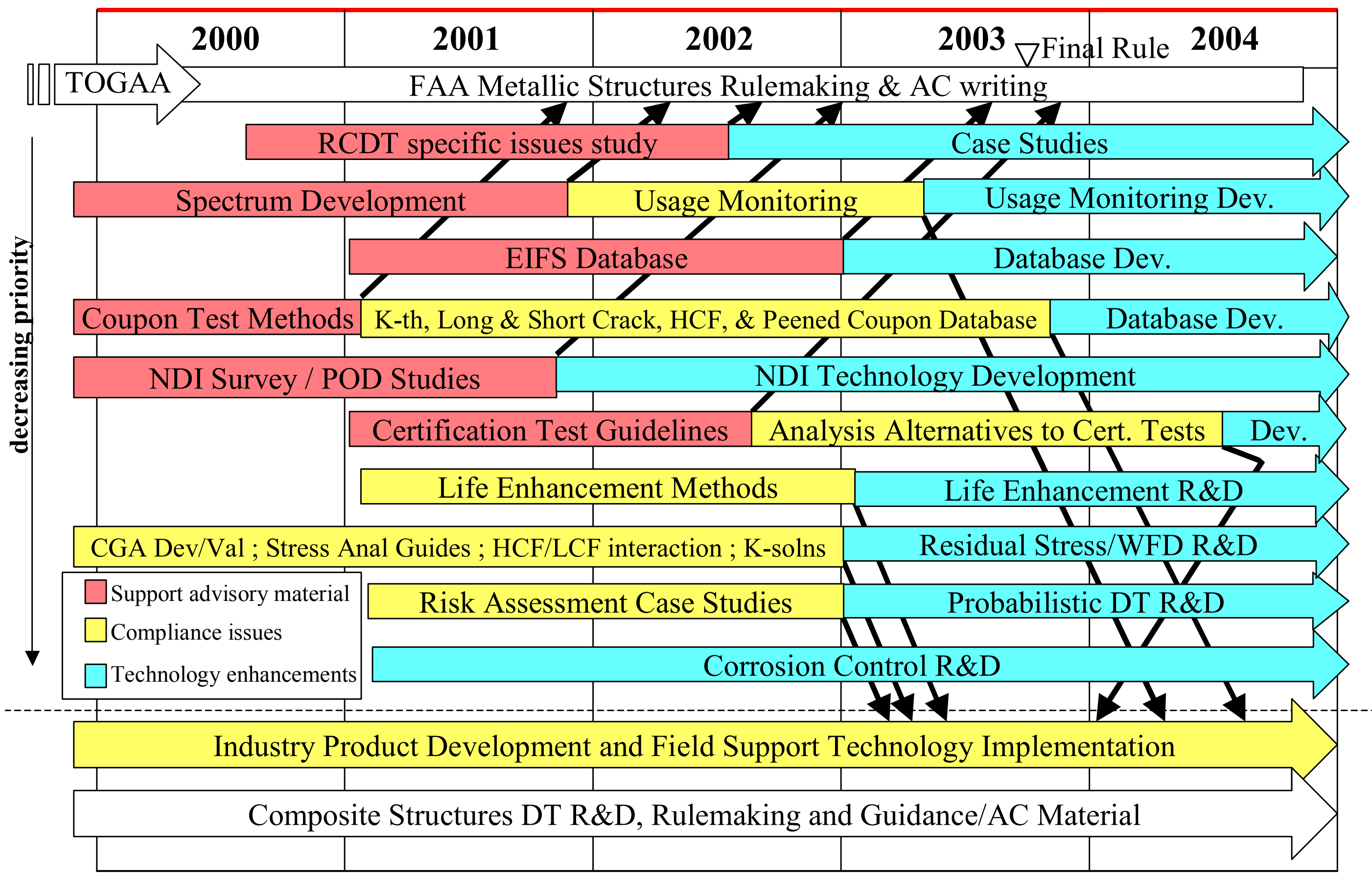
Bell Helicopter

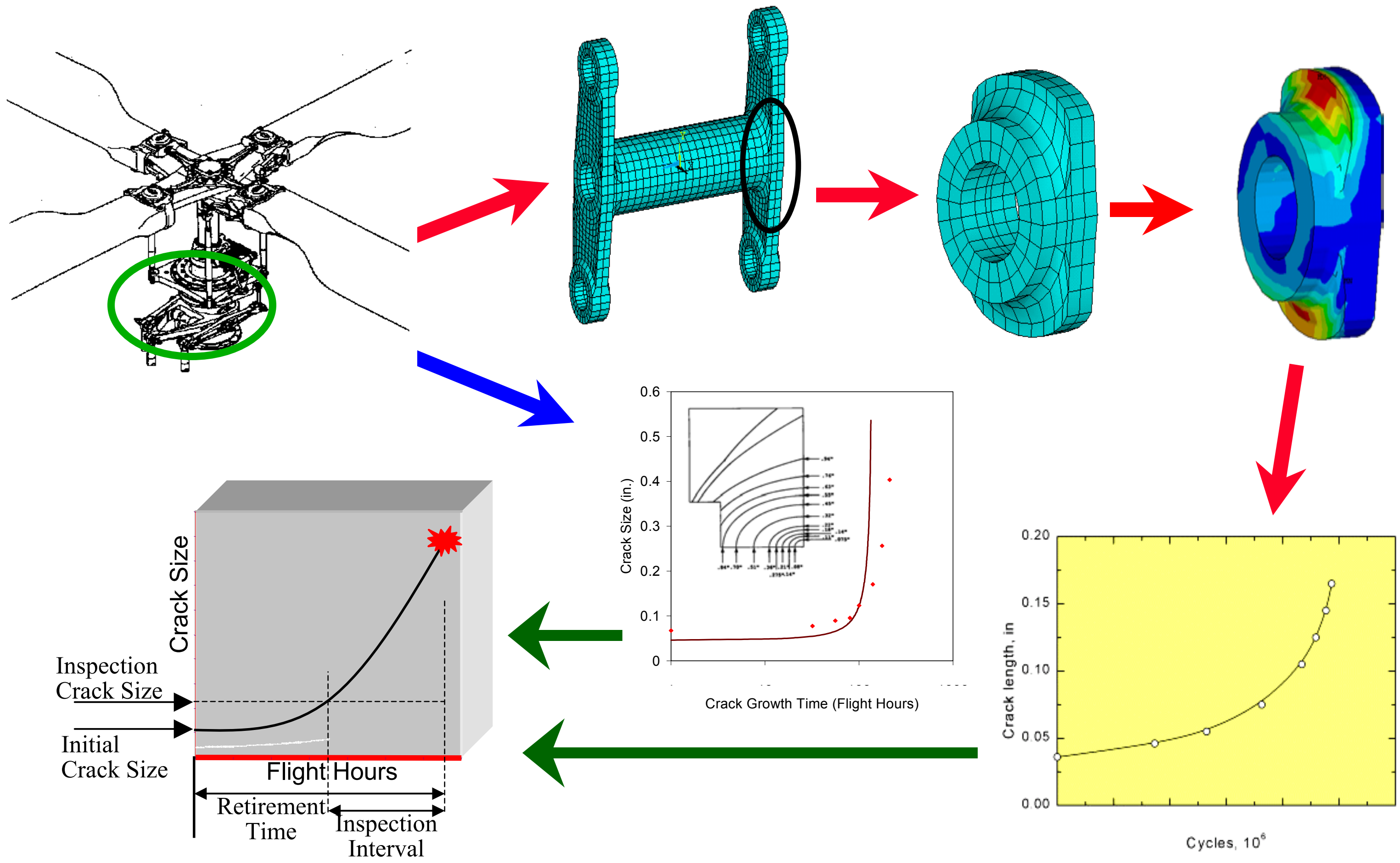
Program Background

ROTORCRAFT DAMAGE TOLERANCE (RCDT) ROADMAP



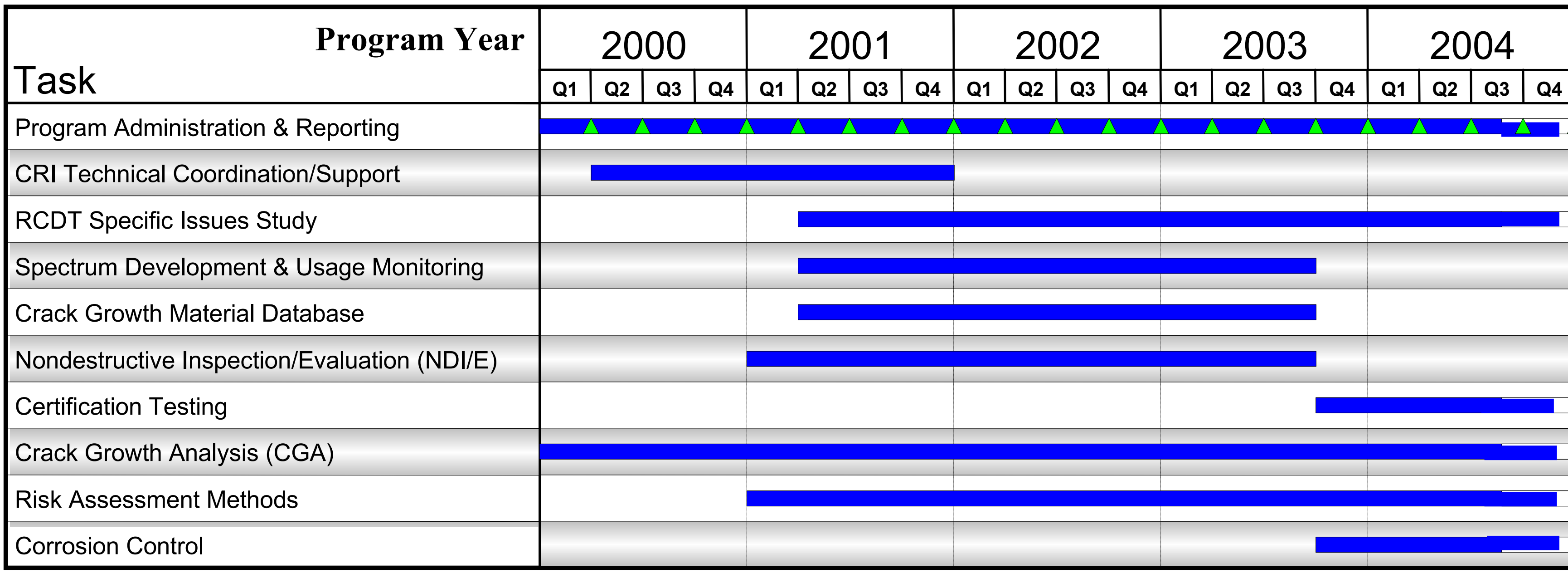
How Does It Work?

FATIGUE CRACK GROWTH ANALYSIS METHODS AND VALIDATION



Technical Objective:

The objectives of this industry wide effort are to conduct metallic damage tolerance (DT) research based on the RCDT Roadmap and to enhance safety of rotorcraft structures, reduce operating cost, develop technology and support guidance material to satisfy emerging DT requirements for commercial & military rotorcraft.



Completion of 2004 program requires approval of requested planned performance extension to the end of September 06 .

Prioritized List of Roadmap Areas (RA)

Indicating the Level of Effort by Principal Members

RITA/FAA RCDT R&D Roadmap Areas	RITA members R&D role M = Major and S = Supporting		
	Bell	Boeing	Sikorsky
1) RCDT specific issues study	**M**	M	M
2) Spectrum development and usage monitoring	**M**	M	S
3) Equivalent initial flaw sizes (EIFS)	S	S	M
4) Crack growth material database	**M**	S	M/S
5) Nondestructive inspection/evaluation (NDI/E)	**M**	S	S/M
6) Certification testing	S	M	S/M
7) Life enhancement methods	S	S	M/S
8) Crack growth analysis (CGA)	**M**	M	M
9) Risk assessment methods	**M**	S	S
10) Corrosion control	**S**	M	S

Items in purple are included in this presentation.

Technical Objectives:

- RA 1: Identify the unique issues and DT technology to address those issues for rotorcraft structures and validate and demonstrate DTA methodology using a full-scale component demonstration
- RA 6: Develop certification testing methodology for dynamic components. Validate methodology using building block approach structural testing of coupons, element level specimens, and full scale or subcomponent level specimens
- RA 8: Use crack growth threshold and crack growth test data from basic coupons as input to crack growth analysis codes to compute the crack growth life of specimens
- RA 9: Develop risk assessment techniques using probabilistic finite element fracture mechanics based analyses of rotorcraft structural elements
- RA 10: Pursue alternative methods to corrosion monitoring (NDE) of specific rotorcraft structures thru the use of in-situ corrosion sensors

Technical Barriers / Challenges

- Practical inspection intervals for critical high cycle fatigue (HCF) dynamic components are a challenge due to high rate of accumulation and varied usage
- No HUMS systems to-date have been certified using the HUMS Advisory circular for maintenance credit
- Crack growth threshold data is lacking and is a critical parameter for DT design of rotorcraft structures especially in a HCF loading spectrum environment
- Improved field inspection methods needed for NDI of thin gage airframes and dynamic components (user friendly, reliable, repeatable, locate damage accurately)

RA 1: Specific Issues Study

Final Joint Specific Issues Report delivered to FAA and TAC to review for public release December 2005. Document includes the following:

- Introduction
- Technical Issues
  - Load Spectra
  - Geometry
  - Material Crack Growth Properties
  - Design
  - Life Enhancement
  - Initial Crack Size
  - Crack Growth Analysis
  - Certification
  - Inspection
  - Risk Assessment/Reliability
- Case Studies
- Roadmap Progress Assessment
- Recommendations for further work
- References

Results:

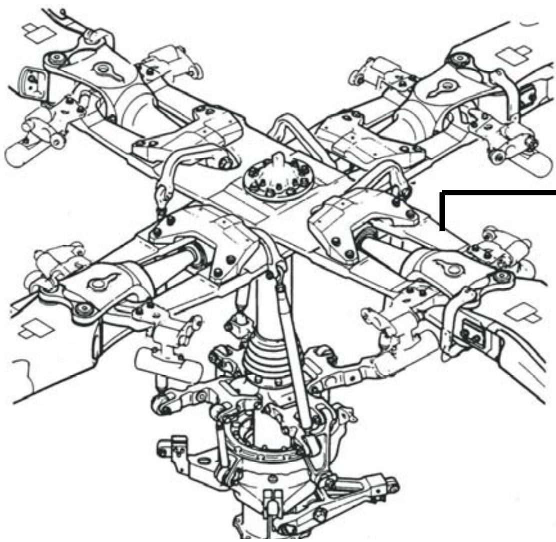
- Assessed TRL progress and current status for each Research Area
- Defined open issues and made recommendations for further research

RA 6: Certification Testing

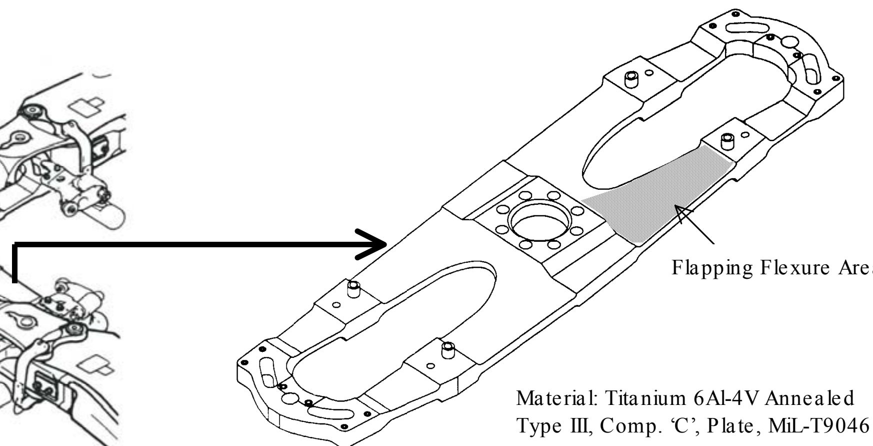
Objective:

Use information obtained from coupon tests and Usage Monitoring and Mission Spectrum task to test element-level specimens. Test a principal structural element (PSE) using available data.

Building Block Approach to Testing a Principal Structural Element

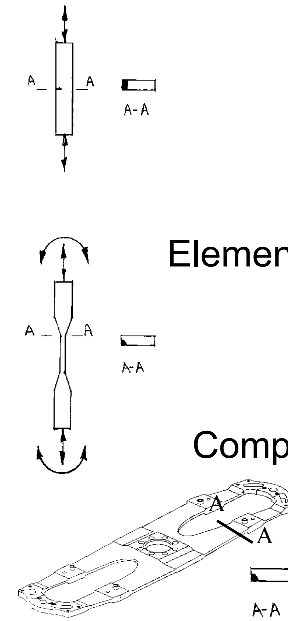


Main Rotor



Yoke

Coupon



Element

Component

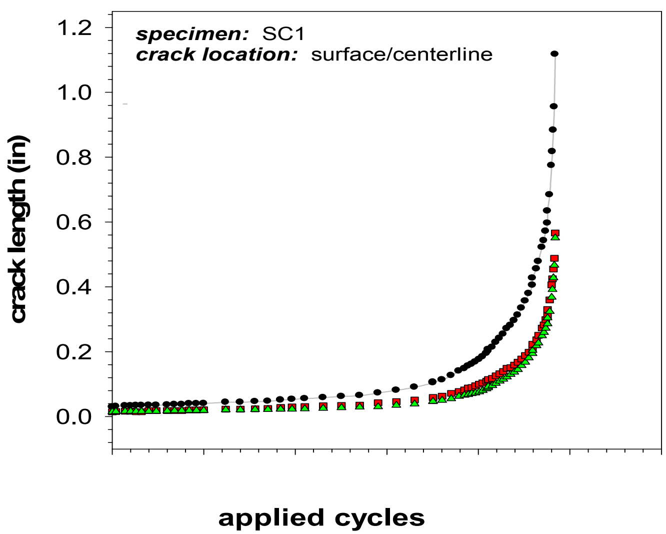
MAIN ROTOR YOKE PSE
(Demonstration Component)

BUILDING BLOCK TESTING PROGRAM

RA 6: Certification Testing

Test Matrix

	Peened	Unpeened	
	Spectrum 1	Spectrum 1	Spectrum 2
Corner Crack (CC)	1	2	1
Center Crack (SC)	1	2	1



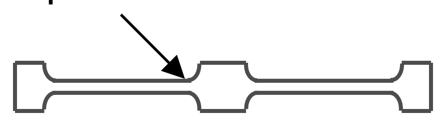
a-N curve for unpeened tension-compression center surface crack specimen.

Accomplishments:

- Developed a test matrix for testing of element-level specimens.
- Completed machining of 16 specimens.
- Completed strain survey for determining notch location.
- Testing initiated on element-level 1 specimens.

Results:

- Strain survey for tension: ε_{max} occurred at 0º position of the radius

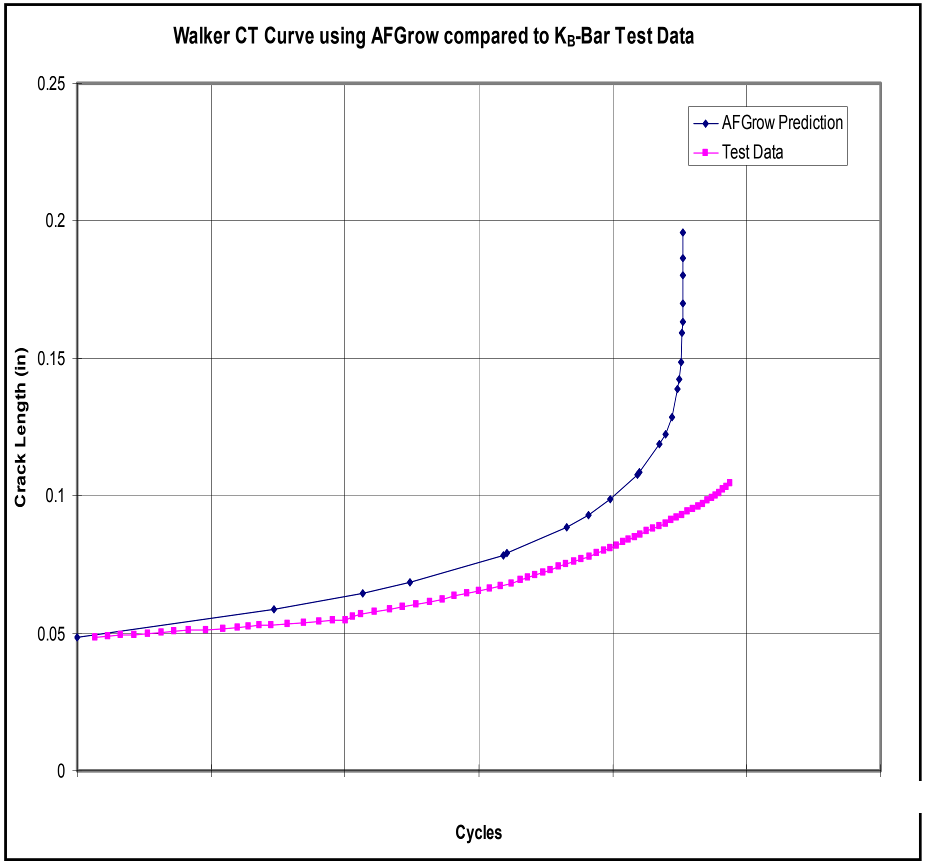


- Learned to control finish grinding of Ti-6Al-4V specimens to avoid high residual tension stress in the surface zone (~ 0.020” depth).

RA 8: Crack Growth Analysis

Objective:

Determine Walker parameters that can be used in AFGrow to analytically predict the life. Correlate this predicted life with crack growth material testing data.



Accomplishments

Walker parameters for CT specimens have been developed and are being correlated with the other specimen types to determine any similarity

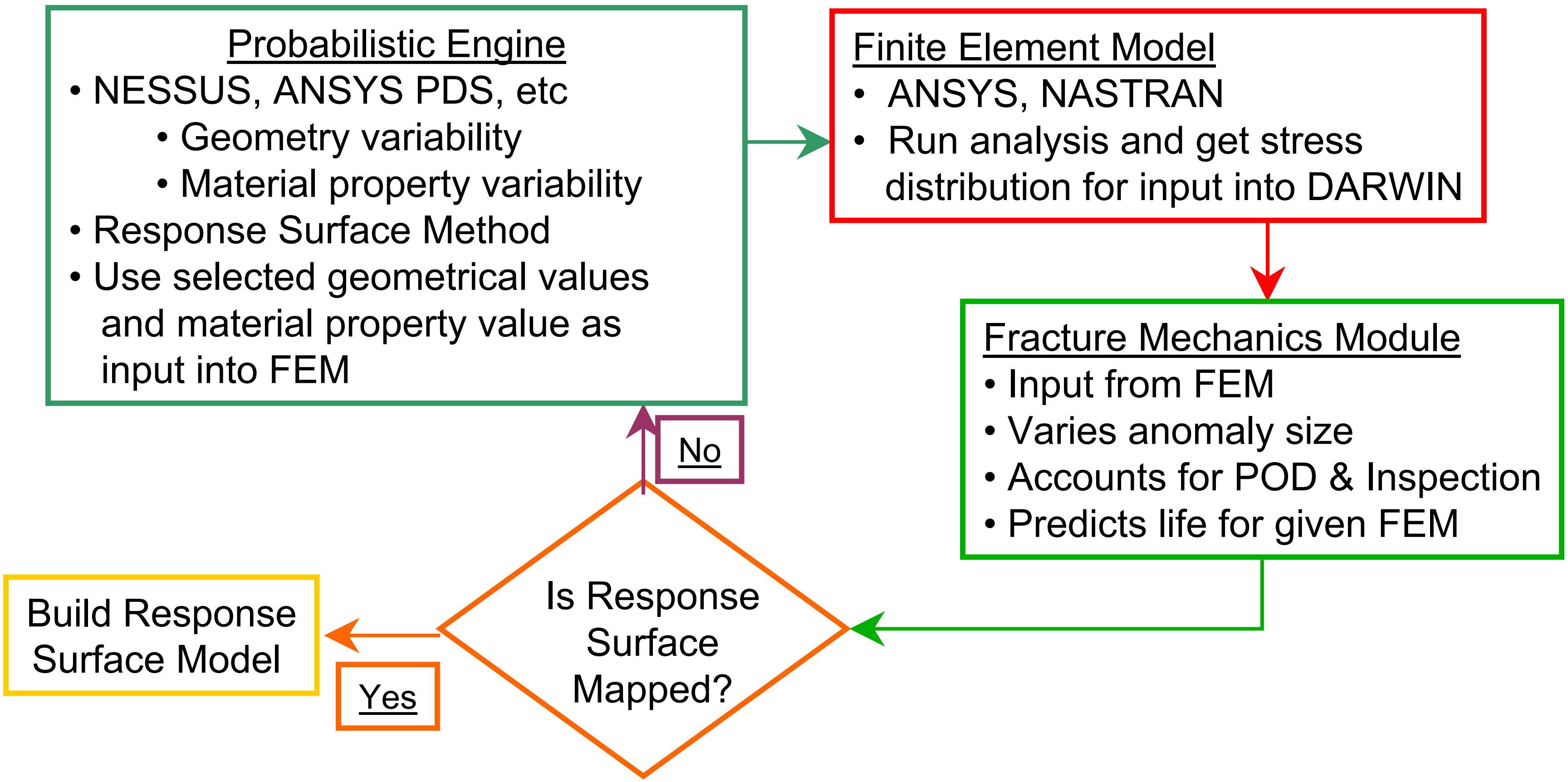
Preliminary Results:

Indications are that the analysis prediction is slightly conservative against testing data.

RA 9: Risk Assessment

Objective:

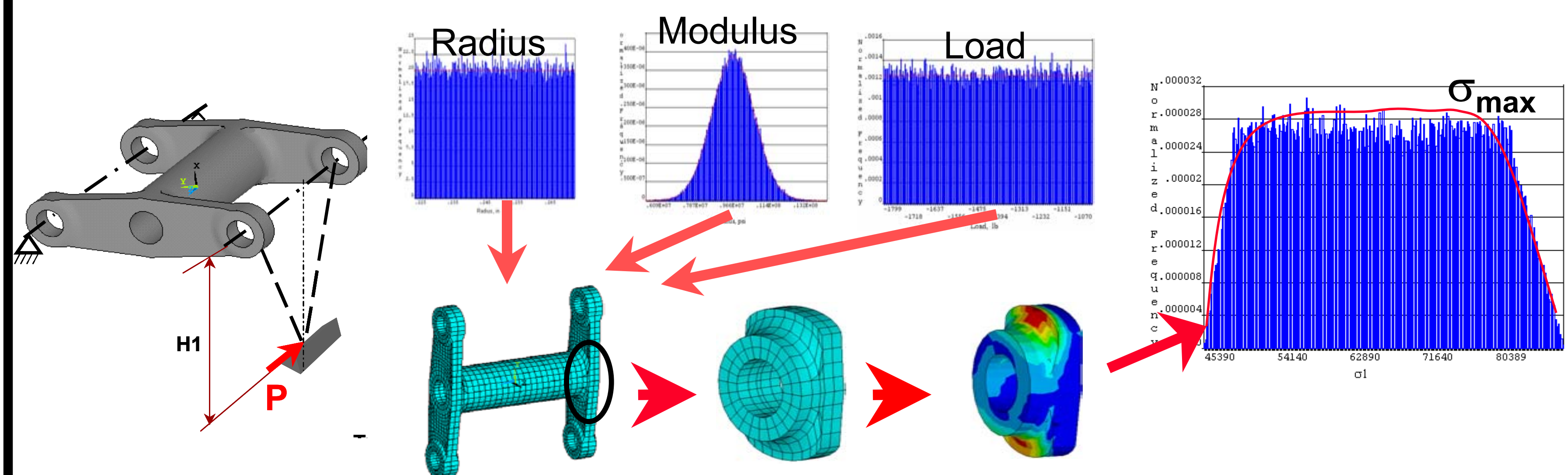
Develop probabilistic methods for determining crack sizes, loads, and strength along with risk assessment methodologies.



RA 9: Risk Assessment

Accomplishments

- A parametric FE model of idler link component completed.
- The kinematics of structural loading application have been analyzed.
- A stress-based probabilistic analysis assessment was completed.
- Performed regression analysis for response surface.
- The model was refined for crack insertion.

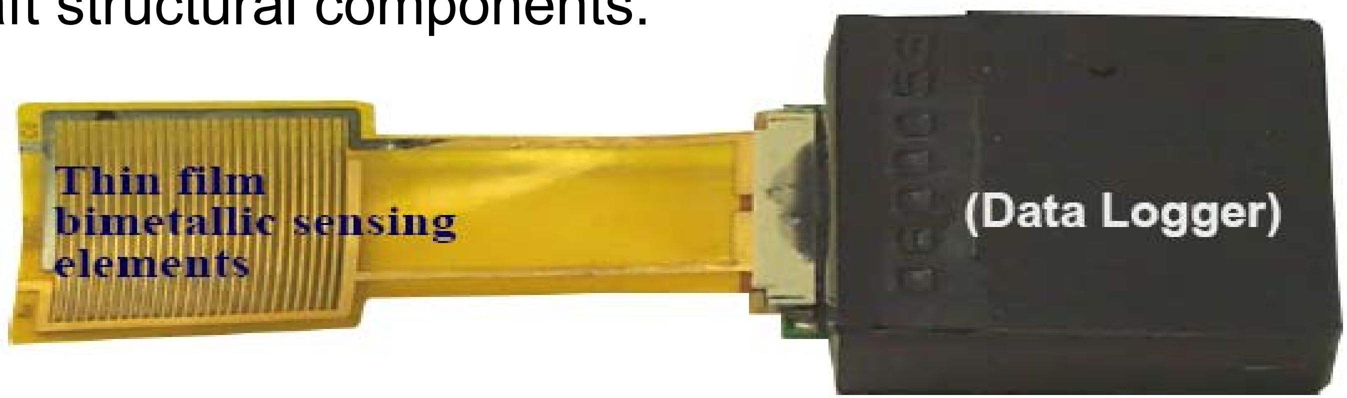


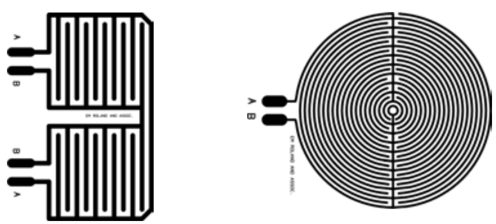
This methodology must be verified using metallic test data to validate each step of the building block approach. Then, because the statistics basis is well established, we can have confidence in the resulting distribution. In another program, this building block methodology has been successfully applied and validated as part of a composite structure study.

RA 10: Corrosion Control

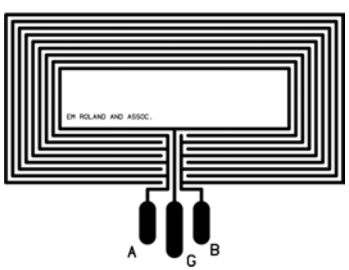
Objective:

Analyze and document the use of bondable, leave-in sensor technology for corrosion detection and the monitoring of specific rotorcraft structural components.





Used beneath coatings or in lap joints



Used in fastener area

RA 10: Corrosion Control

What is it good for?

- Active in-situ corrosion detection
  At any point, the data logger can be connected to a computer that can determine the amount of corrosion that the component has experienced.

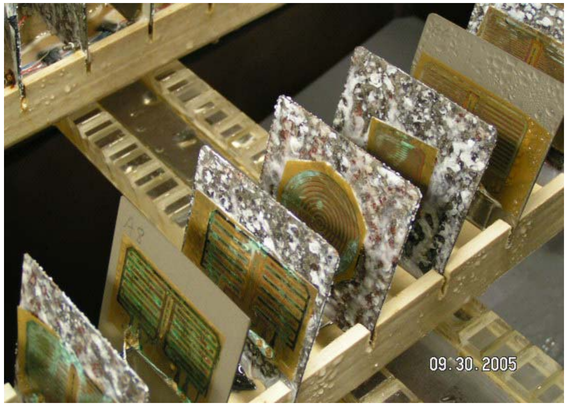
- Localized detection of corrosive environment
  The sensor can be placed in any location that can possibly experience a corrosive environment to determine a more accurate value for corrosion instead of an average for a component or area.

- Detection of the corrosive environment will aid in the monitoring of functional properties and structural strength.

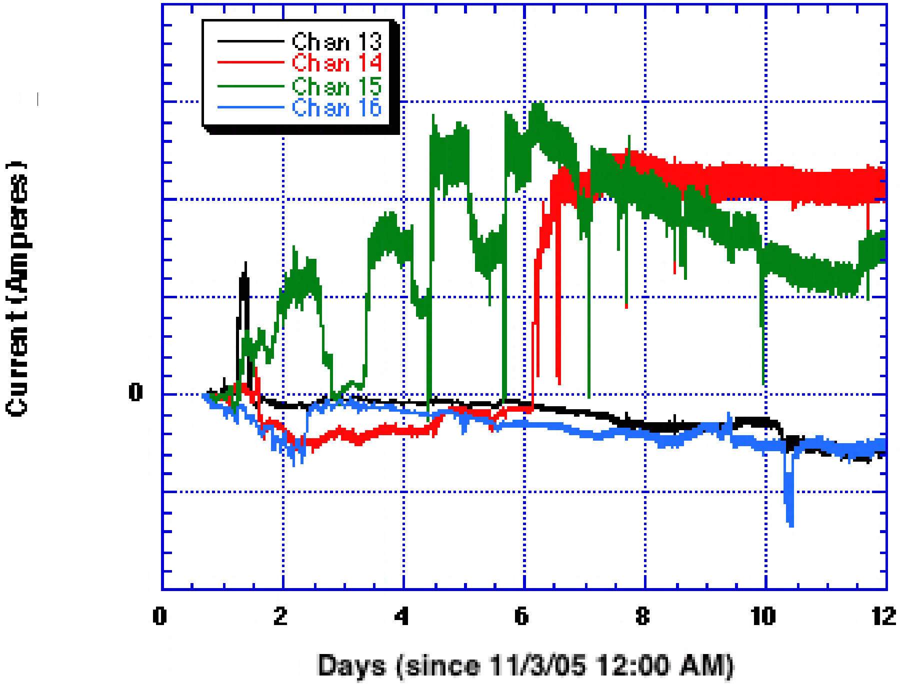
RA 10: Corrosion Control

Accomplishments:

- Corrosion test panel were designed (Al and Ti)
- Corrosion sensors were manufactured
- Procured equipment to monitor and test corrosion sensors
- Final plating of sensors completed
- Salt bath environmental testing completed
- Data package in work



Test panels in salt bath environment



Results:

- Thin-film sensors show promise for real-time detection of corrosion
- Bimetallic sensor design performed best
- Cu-Ni sensors showed longest life
- In this study, sensors were hard-wired to analog multiplexer system. Remote sensing was not evaluated, but is an area of interest for future study.

Accomplishments during PY2004 to Date

- ✓ Delivered Final Joint Specific Issues Report
- ✓ Design of element-level yoke specimen completed
- ✓ Finalized load Spectrum for testing element level yoke specimens
- ✓ Test matrix for element-level specimens completed
- ✓ Element-level specimens machined and delivered to SwRI for testing
- ✓ Three of seven element coupons have been tested
- ✓ Designed, developed and tested a large matrix of thin film corrosion sensors in a representative salt fog environment
- ✓ Completed a feasibility study of probabilistic analysis of a rotorcraft dynamic component
- ✓ Preparing final data packages

Participation and Coordination for Bell RCDT Tasks

Lead Engineers:

- David Yeary - PI, Program Administration and CRI Coordination
- Dr. Xiaoming Li – Program Administration Support
- Dr. Bogdan Krasnowski/Dr. Xiaoming Li - Certification Testing
- Ed Hohman - NDI Technology Development
- Charles Fisher - NDI Technology Development
- Dr. Xiaoming Li - Risk Assessment/Probabilistic Methods
- Dr. Eric Nottorf – CRI Tech Manager

Industry Participation:

- Boeing, Sikorsky
- Subcontractors: Metcut (Testing), SwRI (Testing), River City Associates, Inc. (Corrosion), E M Roland and Associates (Corrosion)

Note: Dr. Bogdan Krasnowski participates in a supporting role as the Bell Technical Resource Specialist on Damage Tolerance